An Observing System Simulation Experiment using both MM5 and WRF: experiment configuration and preliminary results

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ABSTRACT

Recent studies suggest that the accurate representation of the low-level water vapor is crucial for quantitative precipitation forecast. However, mesoscale observations of moisture usually are not available for most regions around the world. An Infra-Red Sounding (IRS) Mission on the Meteosat Third Generation (MTG) would provide high-resolution (in both space and time) temperature and water vapor information. Assimilating these observations into a mesoscale model is expected to improve skills in regional weather forecast. To evaluate such potentials, quantitative analyses of the added values of the IRS candidate mission for regional forecasts are performed by the means of Observing System Simulation Experiment (OSSE).

An OSSE of a dryline and convective storms occurred on June 11, 2002 is conducted to examine the potential value of water vapor and temperature observations derived from the hyperspectral IRS instrument. A 24-h 4-km high-resolution nature or "truth" run is generated using the Penn-State University/National Center for Atmospheric Research (NCAR) Mesoscale Model Version 5 (MM5). Observations of air temperature and water vapor mixing ratio simulated from the "truth" and the retrieved temperature and moisture profiles from simulated IRS are assimilated using the Weather Research and Forecasting (WRF) variational data assimilation system (WRF-Var). Forecasts are carried out using the WRF model to assess the impact of the simulated observations.

The preliminary results show that assimilating moisture observations into WRF improves the short-term forecasts. In some experiments, although only temperature and humidity observations are assimilated, reasonable analysis increments in wind through the background error covariance are produced. It is suggested that some wind observations, such as radiosonde observations, can be used to constrain the wind analysis in order to further improve the forecast.

1. Introduction

Recent studies suggest that the accurate representation of the low-level water vapor is crucial for quantitative precipitation forecast (e.g., Crook 1996, Xue et al. 2006). When realistic mesoscale details of the horizontal variations in moisture and surface moisture availability are included, pronounced improvements in forecast skills for convective events can be achieved (e.g., Koch et al. 1997; Parsons et al. 2000; Weckwerth 2000, 2004).

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However, mesoscale observations of moisture usually are not available for most regions around the world. EUMETSAT Delegations at the 46th PAC meeting commented that inclusion of an IRS Mission on the Meteosat Third Generation (MTG) would be a new capability, when compared to the Meteosat Second Generation (MSG). The IRS Mission on MTG will provide high-resolution (in both space and time) temperature and water vapor information. Utilizing these observations in mesoscale model may improve skills in regional weather forecast. To evaluate such potentials, quantitative analyses of the added values of the IRS candidate mission for regional scale forecasts are performed by the means of OSSE.

2. Overview of the selected case

In this study, a convection case on 11 June 2002 during the International H2O Project (IHOP_2002, Wechwerth et al. 2004) is selected. On 11 June 2002, a dryline formed in the Oklahoma panhandle in the late afternoon. Although most numerical models predicted convection initiation, no deep convective storm formed near the dryline. This case provides a unique dataset for examining the differences between the numerical model prediction and what actually happened. It is also interesting to see whether or not MTG-IRS retrieved moisture fields can resolve the fine-scale dryline, so that the retrievals can help the model to not over-predict convection along the dryline.

3. Observing system simulation experiment

In this study, we use different models for the nature (or "truth") run and for the data assimilation and forecast runs. In the nature run, the model is the 5th generation Penn-State University/National Center for Atmospheric Research (NCAR) nonhydrostatic Mesoscale Model (MM5, Dudhia 1993). Simulated temperature and moisture profiles are then obtained from the nature run, either directly or through MTG-IRS retrieval algorithm (Tjemkes, 2007).

The forecast model is the Weather Research and Forecasting (WRF) model (Michalakes, et al. 2001, Skamarock, et al. 2006). It produces the background fields for the data assimilation experiments and makes forecasts from the analyses. The simulated observations are assimilated using the WRF variational data assimilation system (WRF-Var, Barker, et al. 2006) to produce the analyses. Other observations such as conventional radiosonde can be also simulated from the nature run and assimilated into the background in addition to the MTG-IRS retrieved profiles, so that the added values of the MTG-IRS soundings can be quantified.

a) Model setup

MM5 is a limited-area, nonhydrostatic model, which is designed to simulate mesoscale atmospheric circulation. The model configuration chosen in this study employs 500×500 horizontal grid points with 4-km horizontal resolution and 35 terrain-following height-based vertical levels. The model top is at 50 hPa and the domain covers the central United State continent (Fig.1). The Medium Range Forecast boundary layer scheme (Hong and Pan 1996) and Reisener microphysics scheme (Reisener et al. 1998) are used. The run is fully explicit with no cumulus parameterization scheme used.

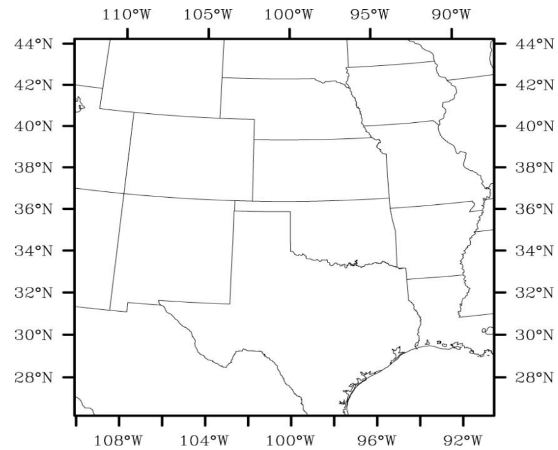

Figure 1 Model domain for MM5.

The WRF model is the next generation mesoscale model designed for cloud and mesoscale applications over a limited area (Michalakes et al. 2001, Skamarock, et al. 2006). The model uses a third order Runge-Kutta time integration, third to fifth order advection operators, and split-explicit fast wave integration conserving both mass and energy. The physics packages chosen for this study include the Noah land surface model (Chen and Dudhia 2001) and the Lin microphysics scheme (Lin et al. 1983, Chen and Sun 2002). For the WRF model and WRF-Var, the domain top is also at 50 hPa and 35 terrain-following mass-based vertical levels are used. The model domain covers a slightly bigger horizontal area than that of MM5. In the low-resolution experiment, the resolution is 36 km with 57x57 horizontal grid points. In the high resolution experiments, the resolution of 4 km and 504x504 horizontal grid points are used.

The data assimilation system WRF-Var developed at NCAR is a unified (global/regional, multi-model, 3/4DVAR) model-space variational data assimilation system (Barker, et al. 2006).

b) Experiment design

The nature run is conducted using MM5. The initial and boundary conditions are interpolated from the 1-degree resolution National Center for Environment Prediction (NCEP) Global Forecast System (GFS) analysis starting at 12UTC 11 June 2002. Conventional observations collected from the Global Telecommunication System (GTS) system are assimilated into the initial fields to enhance the mesoscale features. A 24-h forecast will be treated as the truth state, and the observations will be simulated from the "truth". In addition to the nature run, data assimilation and forecast experiments with low and high-resolution model setup are designed, as listed in Table 1 and Table.2.

Table.1 Lists of experiments for low-resolution model setup.

Experiment	Initial condition for forecast
Control	GFS analysis
MP	BG+Modeled Profiles(t,q)
RP	BG+ Retrieved Profiles(t,q)
RP(q)	BG+ Retrieved Profiles(q)

Table.2 Lists of experiments for high-resolution model setup

Experiment	Initial condition
Control	GFS analysis
MP	BG+Modeled Profiles(t,q)
MPall	BG+Modeled Profiles(t,q,u,v)
RP	BG+ Retrieved Profiles(t,q)
RP(q)	BG+ Retrieved Profiles(q)

In the control experiment, the WRF model is initialized from the GFS analysis at 12 UTC 11 June 2002, followed by a 24-hour forecast. Its 6-h forecast valid at 18 UTC 11 June 2002 serves as the background (BG) in other experiments. In experiment MP, only temperature (T) and water vapor mixing ratio (q) profiles are assimilated. The modification of wind fields relies completely on the background covariance. In experiment RP(q), only q-profiles are assimilated in order to isolate the impact of humidity. In experiment MPall, the horizontal wind u and v, temperature T, and water vapor mixing ratio q are directly drawn from the nature run at 18 UTC June 11, 2002, and in grid points where there are MTG-IRS retrievals. Ideally, this experiment should give the best analysis.

c) The verification

The impacts of MTG-IRS data on the regional scale analysis and forecast are assessed in terms of root-mean-square error (RMSE) between an experiment and

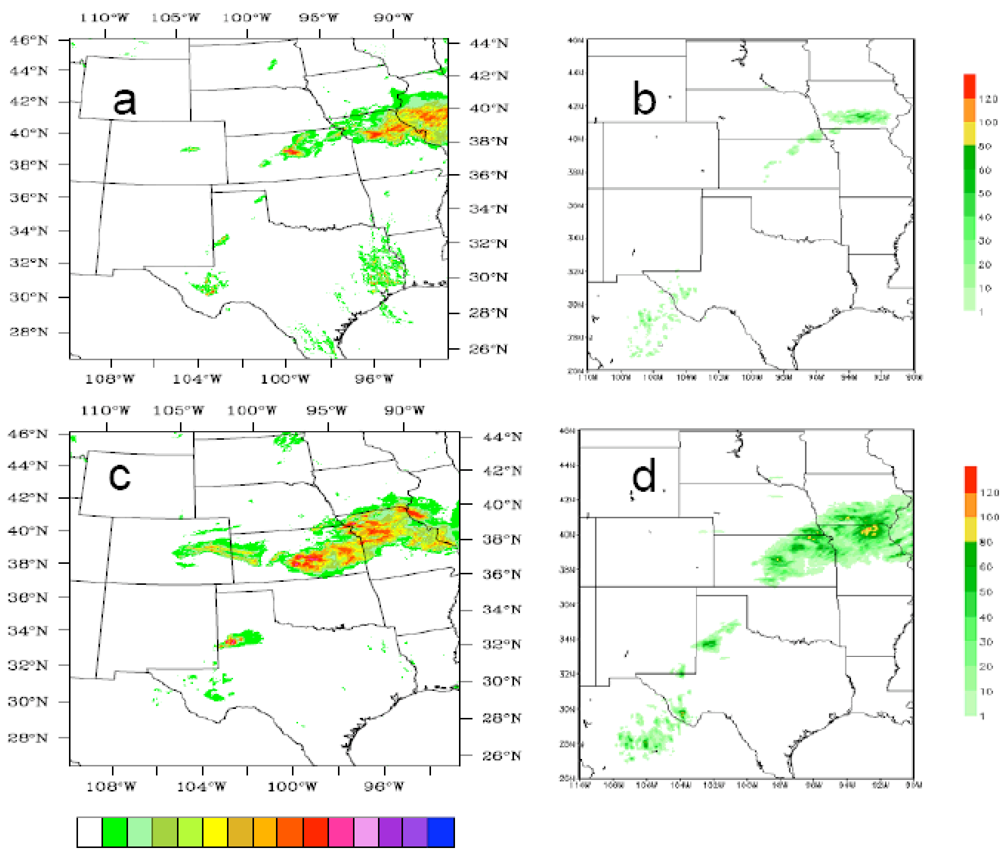

Figure 2 6-h accumulated precipitation in the observation (left) and the nature run (right) valid at 00Z (top) and 06Z (bottom) 12 June 2002. Note that the color scales are different between the observation and the simulation.

the "truth". All the assimilations presented here are done at 18UTC 11 June 2002 using the WRF-Var, followed by an 18-h WRF forecast. Direct comparisons between the precipitation forecasts of experiments and "truth" are also shown.

4. Preliminary results

a) The nature run

Figure 2 compares the 6-h accumulated precipitation of the nature run to the observations. The nature run slightly over-estimates the precipitation. The MM5 nature run simulates quite well the convective storms. It does not produce false alarm on the convection initiation along the dryline.

b) MTG-IRS retrievals

Given the true state, the temperature and water vapor mixing ratio profiles can be retrieved using MTG-IRS sounding algorithm (Tjemkes, 2007). To compare the truth and the retrievals, Figure 3 and 4 show the temperature and humidity distribution in the nature run and the retrievals at 850 hPa, valid at 18UTC 11 June 2002 respectively. In general, the retrievals faithfully represent the relatively large-scale patterns of the real temperature and humidity field.

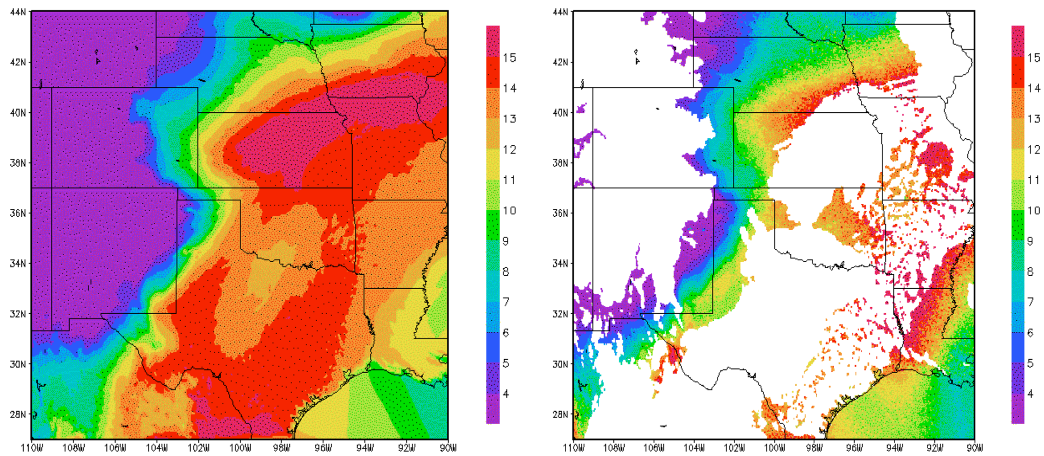

Figure 3 Temperature (K) valid at 18UTC 11 June 2002, of the "truth" (left), and the retrievals (right) on 850 hPa. The white regions have missing values.

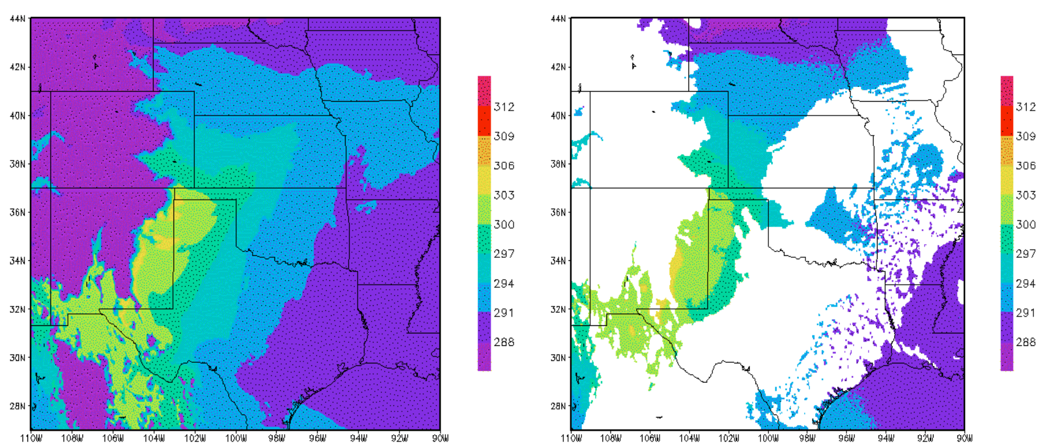

Figure 4 Water vapor mixing ratio (g/Kg) valid at 18UTC 11 June 2002, of the "truth" (left), and the retrievals (right) on 850 hPa. The white regions have missing values.

c) *Results of low-resolution experiments*

The WRF-Var analyses for all data assimilation experiments are performed at 18 UTC 11 June 2002. The analyses are then used to initialize 18-h forecasts using WRF. Figure 5 and 6 give the analysis increment of temperature and water vapor at 850hPa for the experiments MP and RP respectively. It is clear that the assimilation of the IRS retrieved data gives similar spatial patterns in temperature and water vapor increment to the assimilation of the modeled observations.

Using the nature run as the “truth”, the RMSE of analysis and forecast is computed. Figure 7 depicts the vertical profiles of the temperature RMSE for all experiments. For the experiment RP(q), the temperature increment is so small that the RMSE is almost the same as the control experiment. This is because that the humidity has weak correlation to other variables in the background error statistics. As we expected, assimilating model profiles (MP) significantly reduce the errors in all levels. Assimilating the MTG-IRS retrieved temperature and water vapor mixing ratio profiles reduces the error in the middle and lower troposphere. However, it also introduces larger errors in the analysis above 400hPa. Assimilating MTG-IRS retrievals clearly leads to better 12h and 18h forecasts in the middle and lower troposphere.

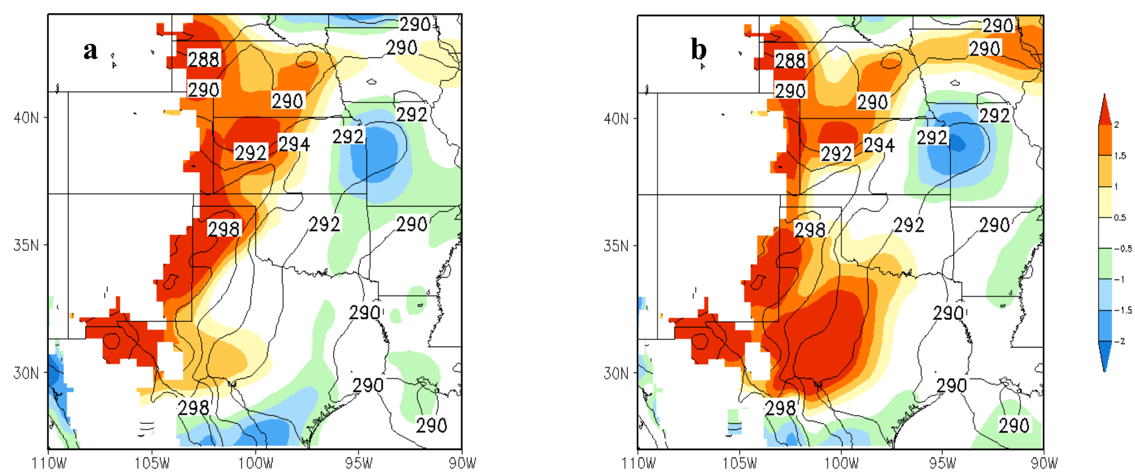

Figure 5 The temperatures increment (unit: K) at 850hPa in experiments a) MP, and b) RP.

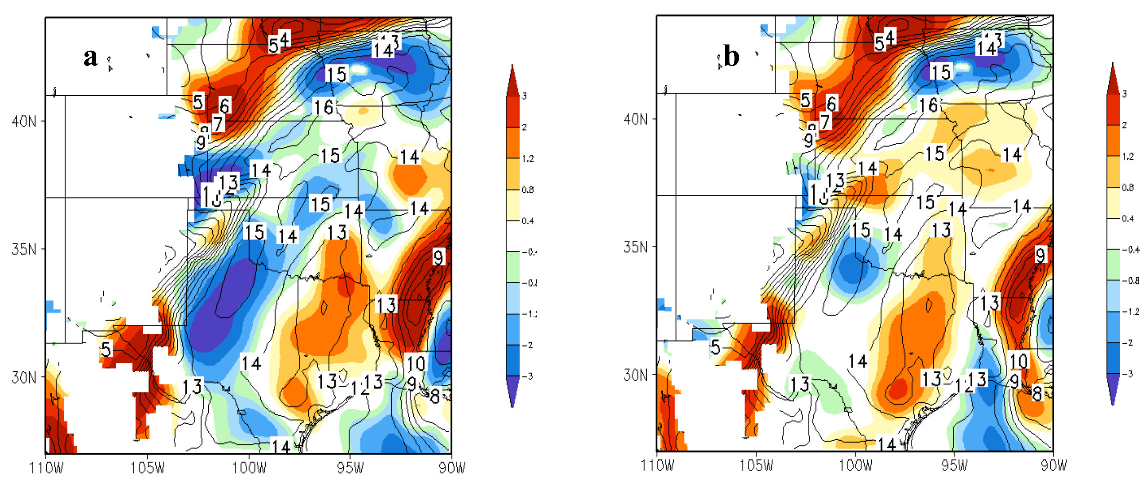

Figure 6 Same as Fig.5 but for water vapor mixing ratio (unit: g/kg).

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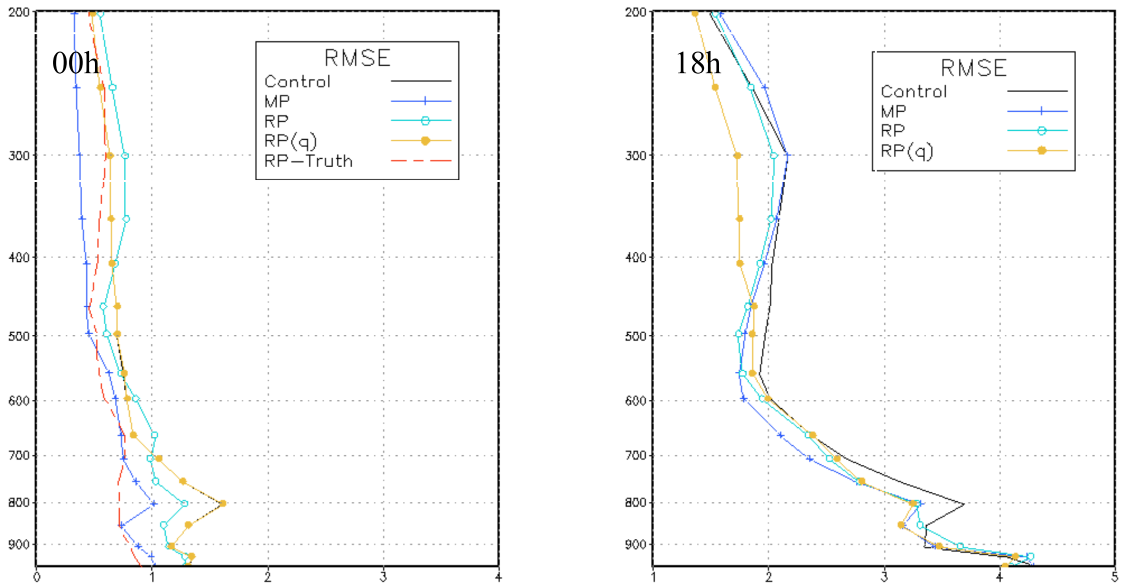

Figure 7 Vertical profiles of the RMSE's in temperature for experiments Control, MP, RP and RP(q), for analyses (00h, left) and 18h forecasts (right). The pink curve in the left panel represents the RMSE of the retrieved data at 0h.

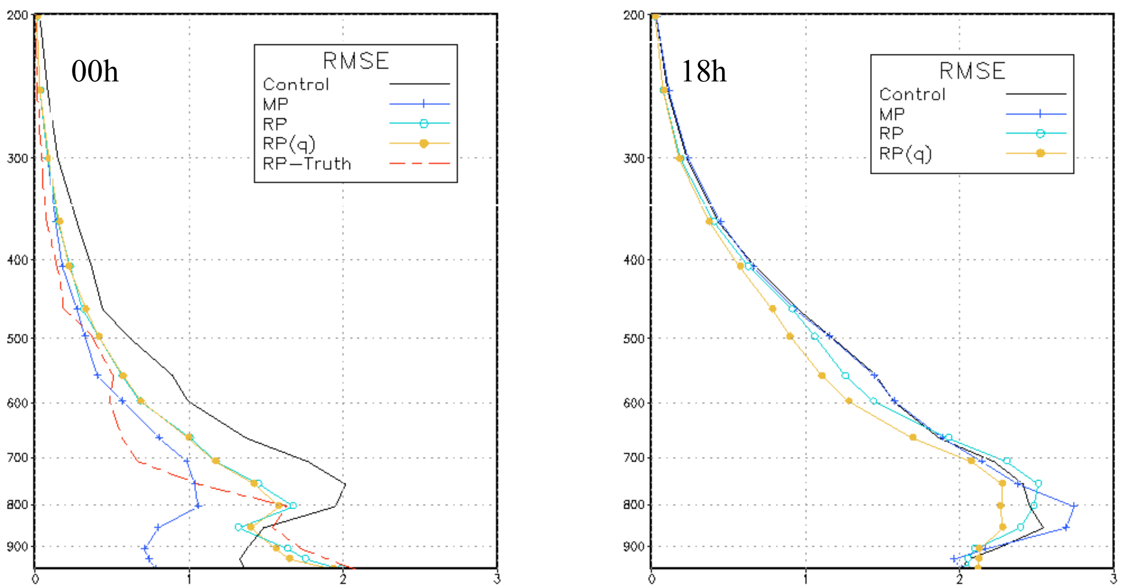

Figure 8 Same as Fig.7 but for water vapor mixing ratio (unit: g/kg).

Figure 8 shows the time evolution of the vertical profiles of water vapor mixing ratio in all experiments. Similar to the temperature fields, assimilating model humidity profiles gives the best analysis. The 18h forecast skill of water vapor is improved (figure not shown), however the errors become comparable among all the experiments at the end of the forecasts except RP(q).

d) Results of high-resolution experiments

One of a main objective of MTG project is to test the impact of high resolution humidity observations on regional forecasts. The experiments with high-resolution model setup are carried out to solid this conclusion.

The vertical profiles of temperature RMSE for all experiments are shown in Fig.9. Same as Fig.7, the RMSE of RP(q) is almost the same as that of Control. MPall and MP give the similar RMSE in the middle and low atmosphere. RP improves the analysis under 700hPa. But only MPall and RP(q) improve the temperature skill during the forecast. Comparing the results between MPall and MP, it indicates the wind constraint is important when retrieved T/q profiles are assimilated. The wind increments are very larger in the RP comparing to RP with low-resolution (figure not shown).

Figure 10 shows the time evolution of the vertical profiles of water vapor mixing ratio in all experiments. It shows that the humidity analysis is improved in MPall and MP at all the model levels. In RP and RP(q), the analysis under 860 hPa is not improved since the retrieved humidity data have larger errors than that of Control. The forecast skill for humidity is improved in RP(q), this results is consistent with the results of low-resolution experiment.

4. Summary and discussion

An OSSE of a dryline and convective storms occurred on June 11, 2002 has been conducted to examine the potential value of water vapor and temperature observations derived from the hyperspectral IRS instrument. In this study, different models are used for the nature (or "truth") run and for the forecast runs. A 24-h nature or "truth" run is generated with a high resolution of 4-km using MM5. Observations of temperature and water vapor mixing ratio simulated from the "truth" and the retrieved temperature and moisture profiles from simulated IRS are assimilated using WRF variational data assimilation system (WRF-Var) followed by 18-h WRF forecasts.

The preliminary results of forecast experiments in both low and high-resolution model setup show that assimilation of moisture observations into WRF helps improve the short-term forecasts. However, when only temperature and humidity observations are assimilated, analysis increments in high-resolution experiments in wind through the background error covariance of WRF-Var are larger than that in low-resolution experiments, and the subsequent forecast is deteoriated. It is suggested that some wind observations, e.g. simulated radiosonde observations in the context of OSSE, should be necessary to constrain wind analysis and to further improve the short-term forecast.

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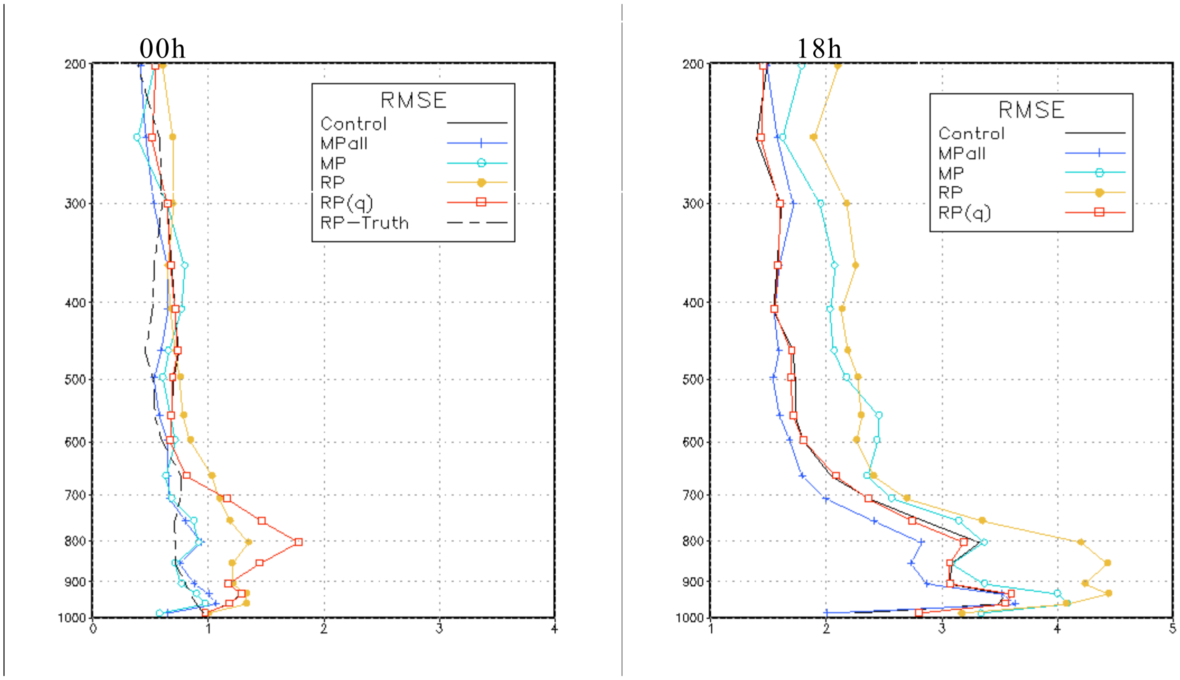

Figure 9 The vertical profiles of the RMSE's at 00h and 18h in temperature for experiments Control, MPall, MP, RP and RP(q).

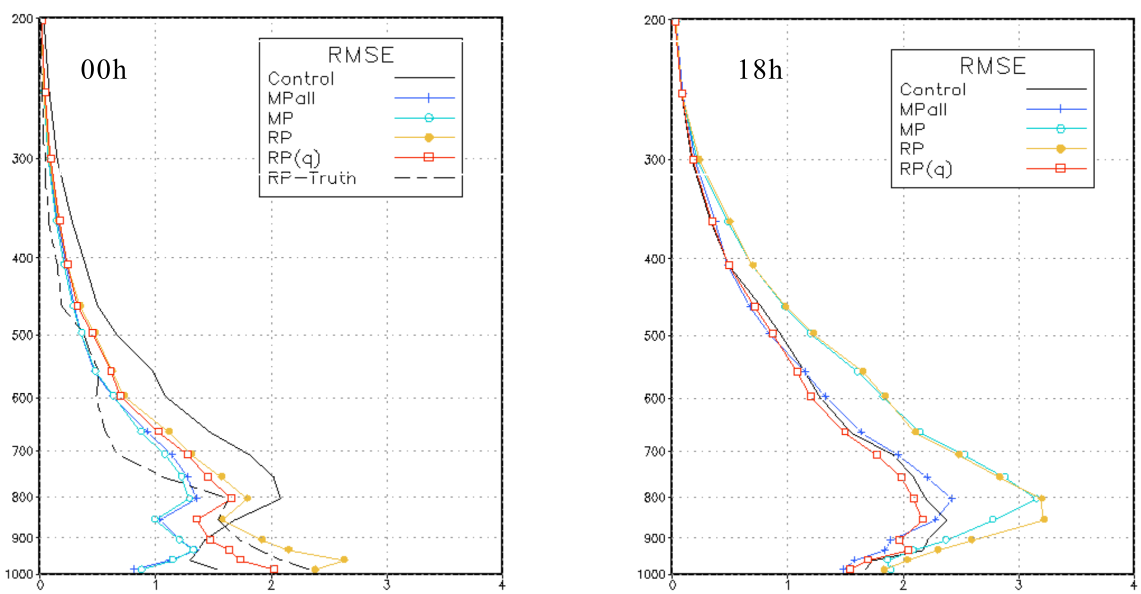

Figure 10 Same as Fig.9 but for water vapor mixing ratio (unit: g/kg).

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